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ISO-SWS SPECTRA OF AGB STARS

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Abstract. In this contribution, we present a few highlights of the guaranteed time program to observe AGB stars with differing chemical compositions and mass loss rates using ISO [1] SWS. We briefly discuss C_2H_2 absorption in C-stars and O-rich stars with the 13 μm dust emission.

1. Introduction

The late stages of evolution of intermediate mass stars provide an interesting test bed for studies of molecule and dust formation, mass loss mechanisms, and interactions between gas and dust. The evolution of these stars depends strongly on mass loss rate and during AGB evolution, the photosphere is gradually enriched in carbon due to the dredge up of nuleosynthesis products. As a consequence, AGB stars are divided into different classes : O-rich (C/O $<$ 1), S-stars (C/O $\sim$ 1) and C-stars (C/O $>$ 1). O-rich and C-rich AGB stars have very different spectra due to the great differences in chemical composition of the photospheric and the circumstellar gas and dust.

In our gauranteed time ISO/SWS program, we have observed a large sample of AGB stars and to be able to study the stars as a function of chemical composition and mass loss rate.

[1]Based on observations with ISO, an ESA project with instruments funded by ESA Member States" (especially the PI countries: France, Germany, the Netherlands and the United Kingdom) with the participation of ISAS and NASA.

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We observed spectra of various classes of stars, ranging from short period O-rich Miras to very long period OH/IR stars, S-stars, optically visible and optically thick C-rich stars, and supergiants. A total of 33 stars have been observed in our program. In a previous paper, we have reported on an early study of the SWS spectrum of the supergiant NML Cyg (Justtanont et al. 1996). Here, we present preliminary results of two classes of AGB stars.

2. Observations

The spectra were obtained using the Short wavelength Spectrometer (SWS, de Graauw et al. 1996) aboard the Infrared Space Observatory (ISO, Kessler et al. 1996). We obtained full grating scans with uninterrupted spectra from 2.3 to 45.2 μm. The average resolution of the spectra ranges from 200 to 800. The data reduction was done by using the data analysis software provided by the SWS Instrument Dedicated Team.

3. C-rich stars

We have detected several molecular bands belonging to HCN and C_2H_2 in all our carbon stars. The prominent bands are at 3.1 and 13.7 μm. We also see molecular bands due to C_3 as well as the 11.3 μm SiC dust feature.

In Fig 1, we present spectra of C-rich stars in the region of 13-15 μm. The spectra show an absorption of C_2H_2 which has Q-branches centred at 13.7 μm. The spectra are arranged in a sequence of increasing mass loss rate from the top to the bottom. It can clearly be seen that the depth of the absorption feature does not correlate with mass loss rate. However, it appears that there is a correlation between the width of the feature and the mass loss rate. Optically visible stars show line profiles which are wider than those with optically thick circumstellar envelopes. i.e., higher excitation temperature can excite lines with higher energies. The most plausible explanation for this is that the lines are formed in, or near, the photosphere of optically visible C-stars. For stars with higher mass loss rates, the photosphere is obscured by the dusty envelope and the absorption line is due to circumstellar shell. Farther from the central star, the excitation temperature is lower, resulting in narrower line widths.

4. Stars with the 13 μm Dust Emission

A subset of O-rich stars in our sample possesses an emission feature at 13 μm which was first seen in IRAS LRS spectra (Vardya et al. 1986) od stars with optically thin dust shells. Sloan et al. (1996) suggested that the feature is seen most often in semi-regular variables of type SRb. Many

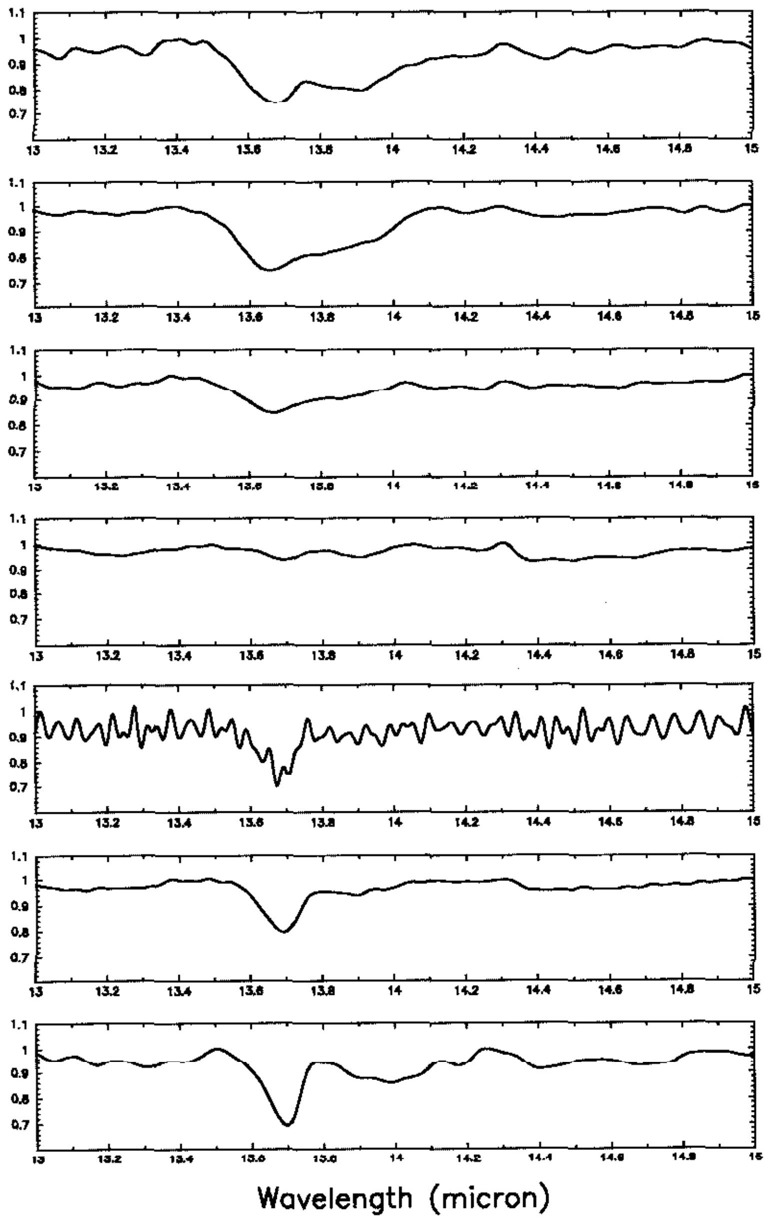

Figure 1. C_2H_2 band in C-rich stars with various mass loss rates. Mass loss increases from top to bottom.

of the stars with this feature have relatively symmetric light curves. The origin of the feature is still under debate. One proposal is that it is due to aluminum oxide dust (Onaka et al. 1989) since it is thought that aluminum oxide is one of the first dust species to condense from the outflow. Another common characteristics of these stars is that they exhibit main line OH maser emission at 1665/1667 MHz which is stronger than at 1612 MHz.

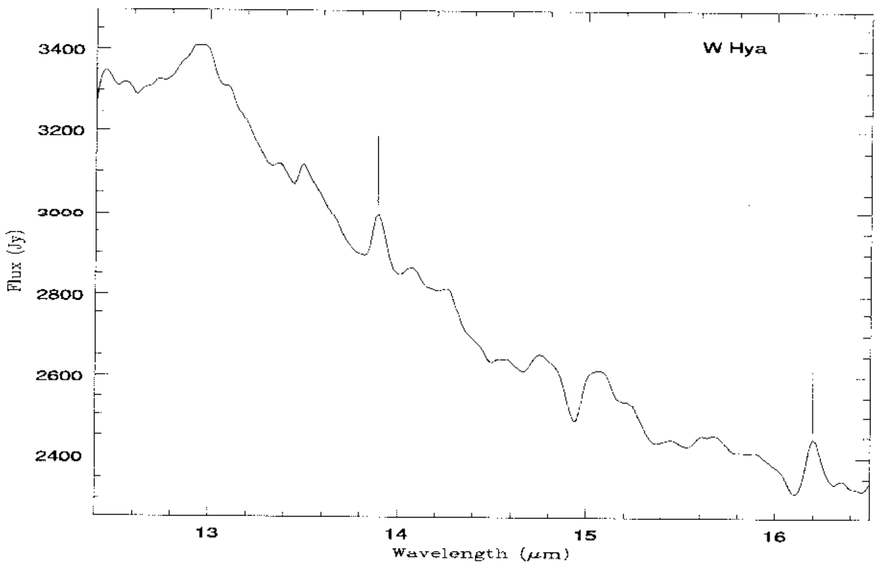

Figure 2. Spectrum of W Hya showing the 13 μm dust emission and the unidentified emission lines marked by vertical lines. The absorption feature at 15 μm is due to CO_2.

The SWS spectra of these stars also reveal other features. We detected two very prominent emission lines previously unseen by IRAS LRS due to its low resolution. Unfortunately, the wavelength range where these two emission lines occur is not accessible from the ground. At present, these lines are unidentified. The spectra obtained so far have too low resolution to determine the wavelengths accurately. However, one firm conclusion can be drawn is that these lines are associated with the 13 μm dust feature. One possible candidate for the line at 13.87 μm is Ca I, but the excitation energy is very high. If this is the case a very strong shock is required to excite the atom. It is possible that we are observing the region where calcium has not yet condensed into dust grains. These lines can then be used to probe conditions, i.e., temperature and density, of the dust forming region. In our further studies, we will observe these stars at higher resolution in order to accurately determine the wavelengths which will hopefully lead to firm identification of the responsible species. For the present, we speculate that these lines are shock excited lines of common elements since they are present in all stars with the 13 μm emission feature in our sample.

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Darlow: Are higher resolution SWS spectra planned for the unidentified emission lines in the 13μm region?
Justtanont: We will observe a total of 19 stars using the full SWS resolution and we plan to observe a selected number of stars with FP on these emission lines.

Bakker: In computing synthetic spectra to fit the observation, the line positions are fine, but not the intensities. Did you include optical depth effects to compute line profiles?
Justtanont: No, we only assume thermodynamic equilibrium of a thin shell in our model.

Olofsson: For NML Cyg, have you attempted to convert the circumstellar CO, CO_2, H_2O, and OH radical column densities into abundances?
Justtanont: $x(CO) \sim 2.5 \times 10^{-4}$; $x(CO_2) \sim 3 \times 10^{-5}$; $x(H_2O) \sim (3 \rightarrow 5) \times 10^{-4}$. We did not estimate the column density for OH.